Comparison of Resource and Energy Yield Assessment Procedures 2011-2015

What have we learned and what needs to be done?

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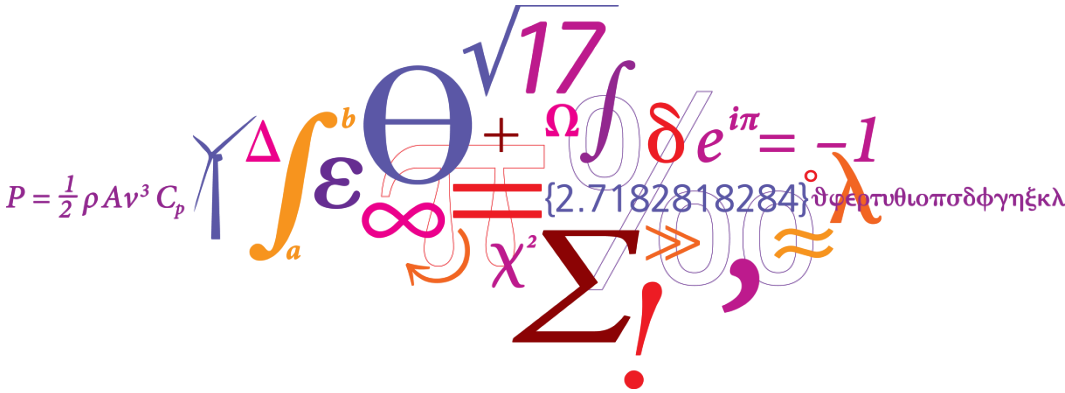
EWEA 2015
Paris, France



DTU Wind Energy
Department of Wind Energy

Comparison of **R**esource and **E**nergy **Y**ield **A**ssessment **P**rocedures

EWEA CREYAP concept

- Industry benchmarking
- In-house training and R&D
- Identification of R&D issues

Issues for today

- Review of the 4 CREYAP exercises
  - Methodologies
  - Magnitudes and uncertainties
  - Modelled vs observed yields
- Mostly conclusions presented here
  - Keep in mind the limited data set
  - Prioritised list of actions
  - Reference list in handout

CREYAP history

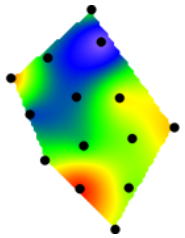
- Onshore Part 1, Bruxelles 2011
  - Scotland W, 14 × 2 MW (28 MW)
- Onshore Part 2, Dublin 2013
  - Scotland E, 22 × 1.3 MW (29 MW)
- Offshore Part 1, Frankfurt 2013
  - Gwynt y Môr, 160 × 3.6 (576 MW)
- Offshore Part 2, Helsinki 2015
  - Barrow, 30 × 3 MW (90 MW)

Summary

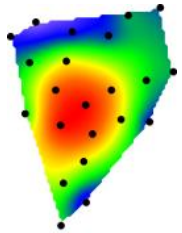
- 157 submissions from 27 countries
  - 97 for onshore
  - 60 for offshore

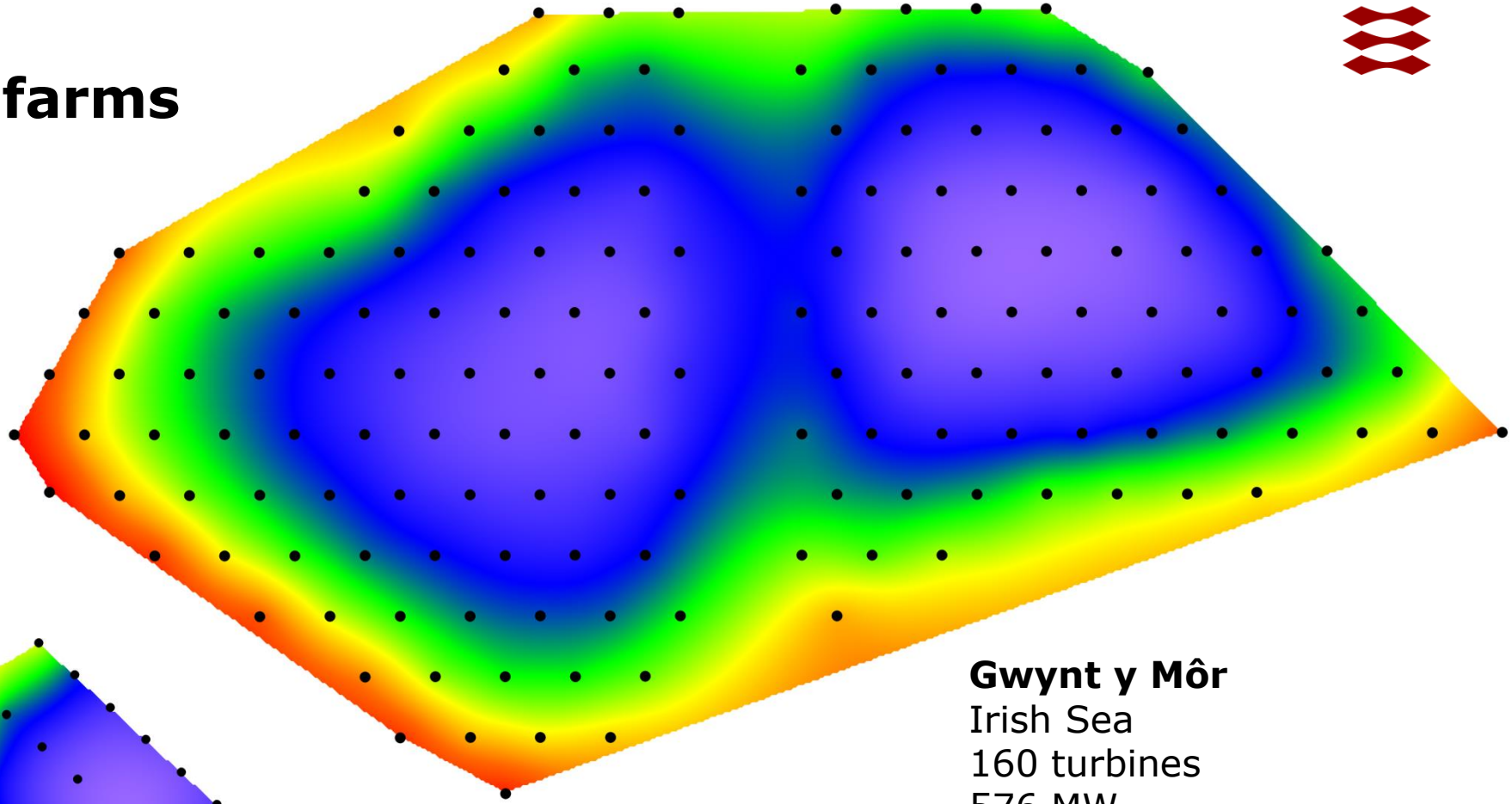
The CREYAP wind farms

Hilly/complex
Scotland W
14 turbines
28 MW



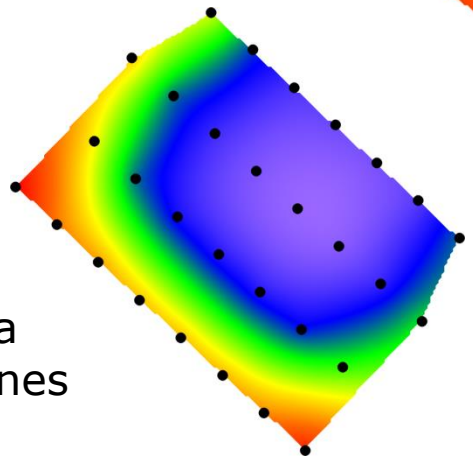
Hilly/complex
Scotland E
22 turbines
29 MW





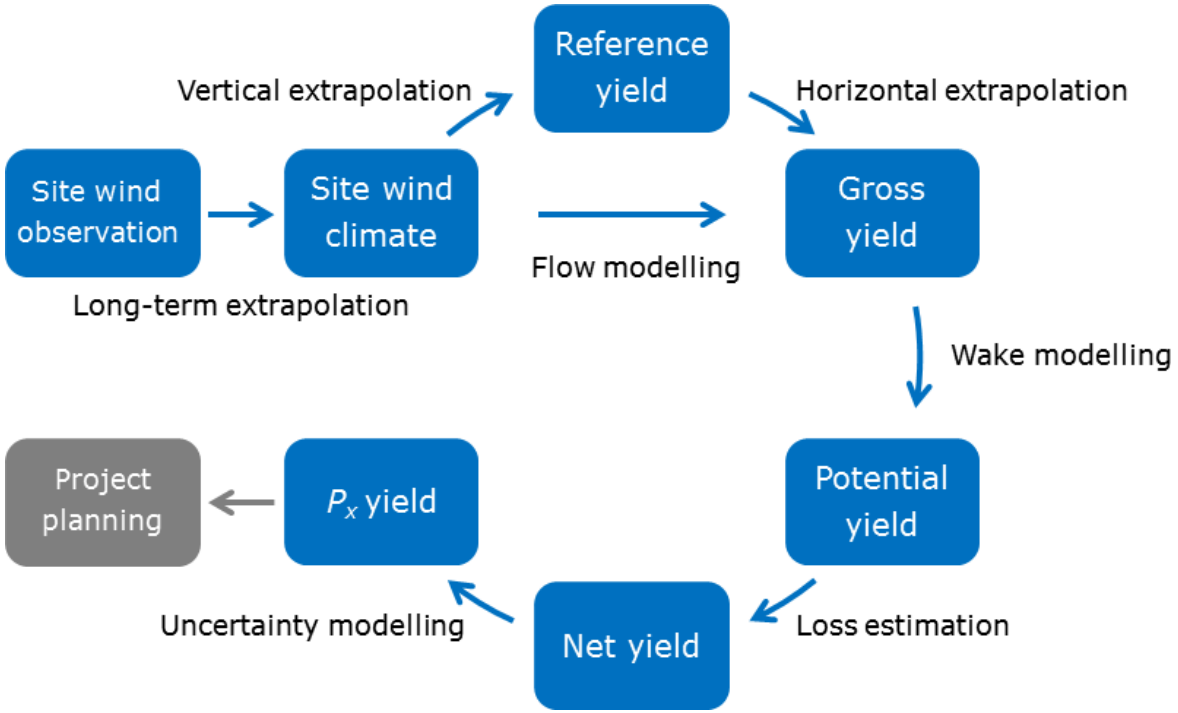
Gwynt y Môr
Irish Sea
160 turbines
576 MW

Barrow
Irish Sea
30 turbines
90 MW



- Estimated wind turbine yields
  (local color scales from P_{min} to P_{max})

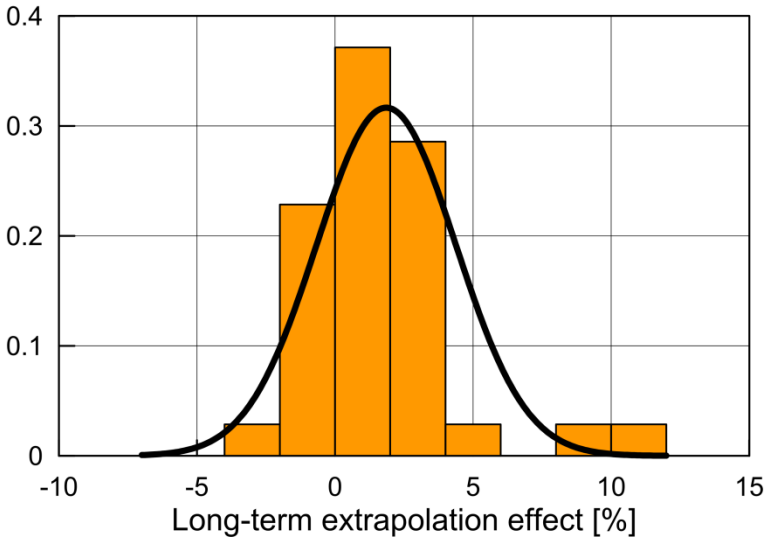
Methodology and limitations

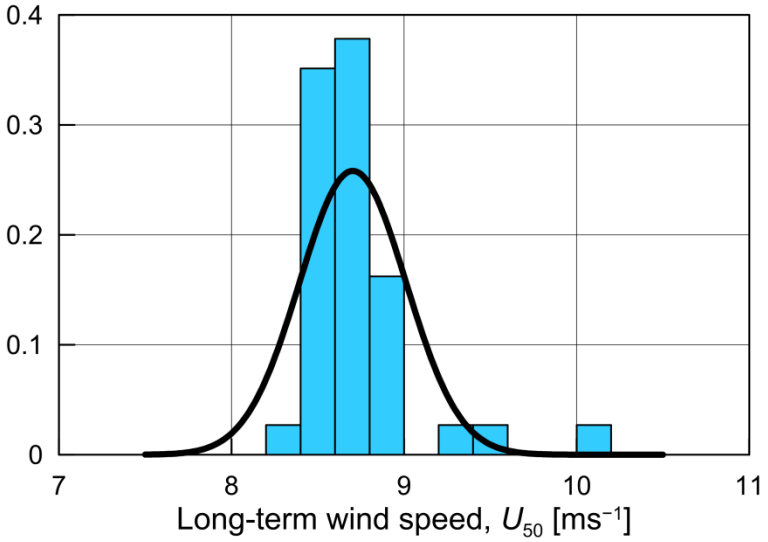


- *N* teams make predictions for one wind farm
- Input data are identical; methods different
- Mean and spread compared for each step

- Open exercises, no team requirements
  - Results may not reflect industry
- Blind test with independent evaluation
  - Team identities unknown to evaluator
  - Peer review of evaluations
- Results based on group statistics
  - Limited data in forms and groups
  - Statistics sensitive to outliers
  - Non-parametric and normal stat's
- Definitions
  - Bias ≡ difference between average of estimates and observations (mean)
  - Uncertainty ≡ standard deviation (spread) of distribution of estimates.

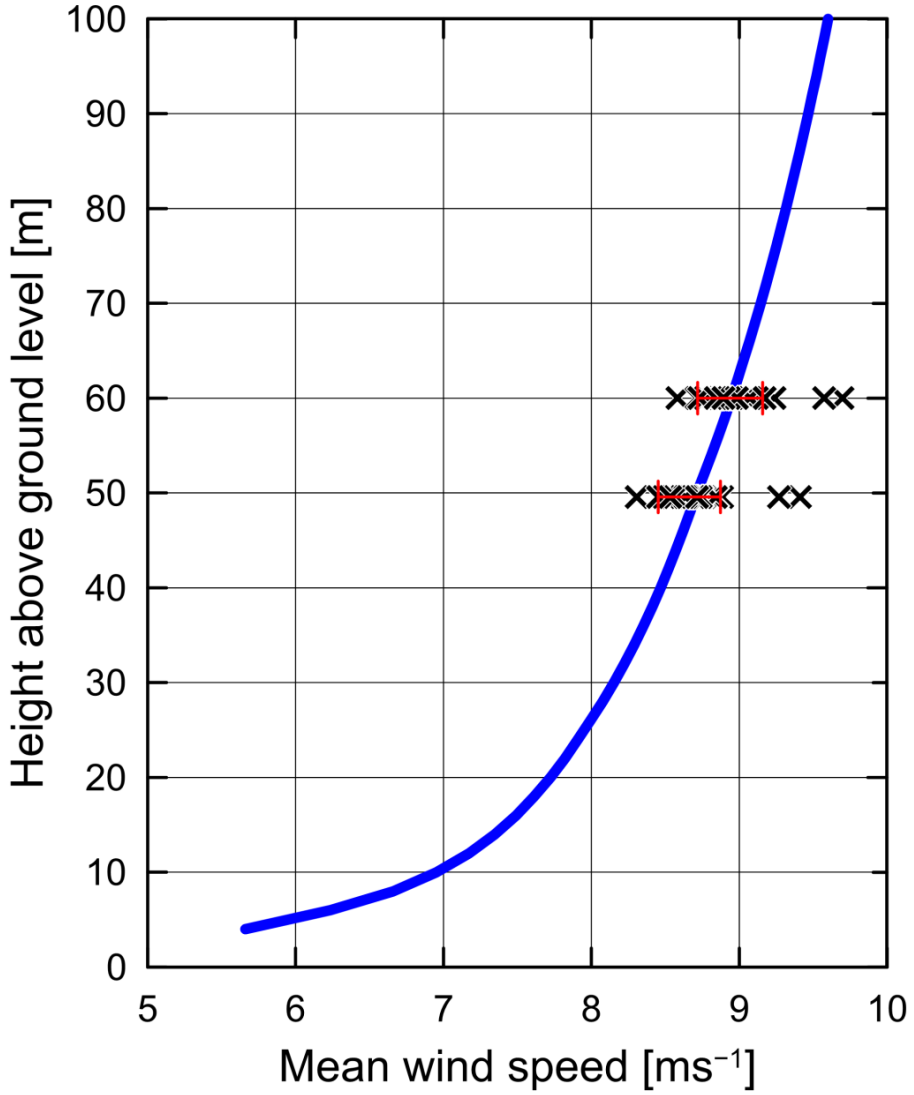
1 Long-term extrapolation





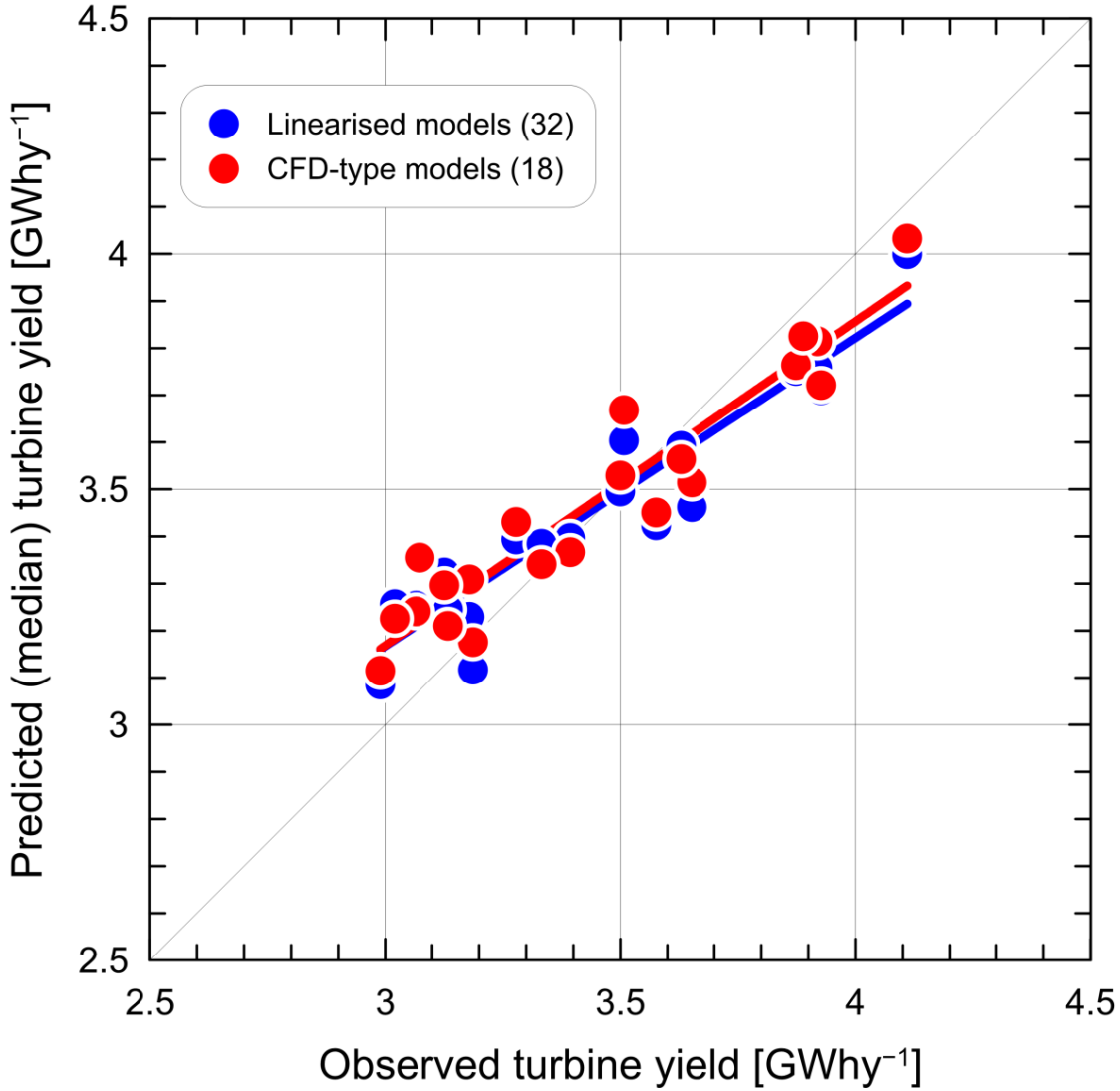
- LT extrapolation effects small and uncertain
  - 0 to 1.8% on average (onshore)
  - −2.2 to 0.2% on average (offshore)
- Methodologies used
  - Not well defined at all
- Uncertainty
  - 80 to 280% (CV)
- Special issues
  - 5-13% outliers
- CREYAP results
  - Difficult analysis of ill-defined methods
  - Inconclusive results.

2 Vertical extrapolation



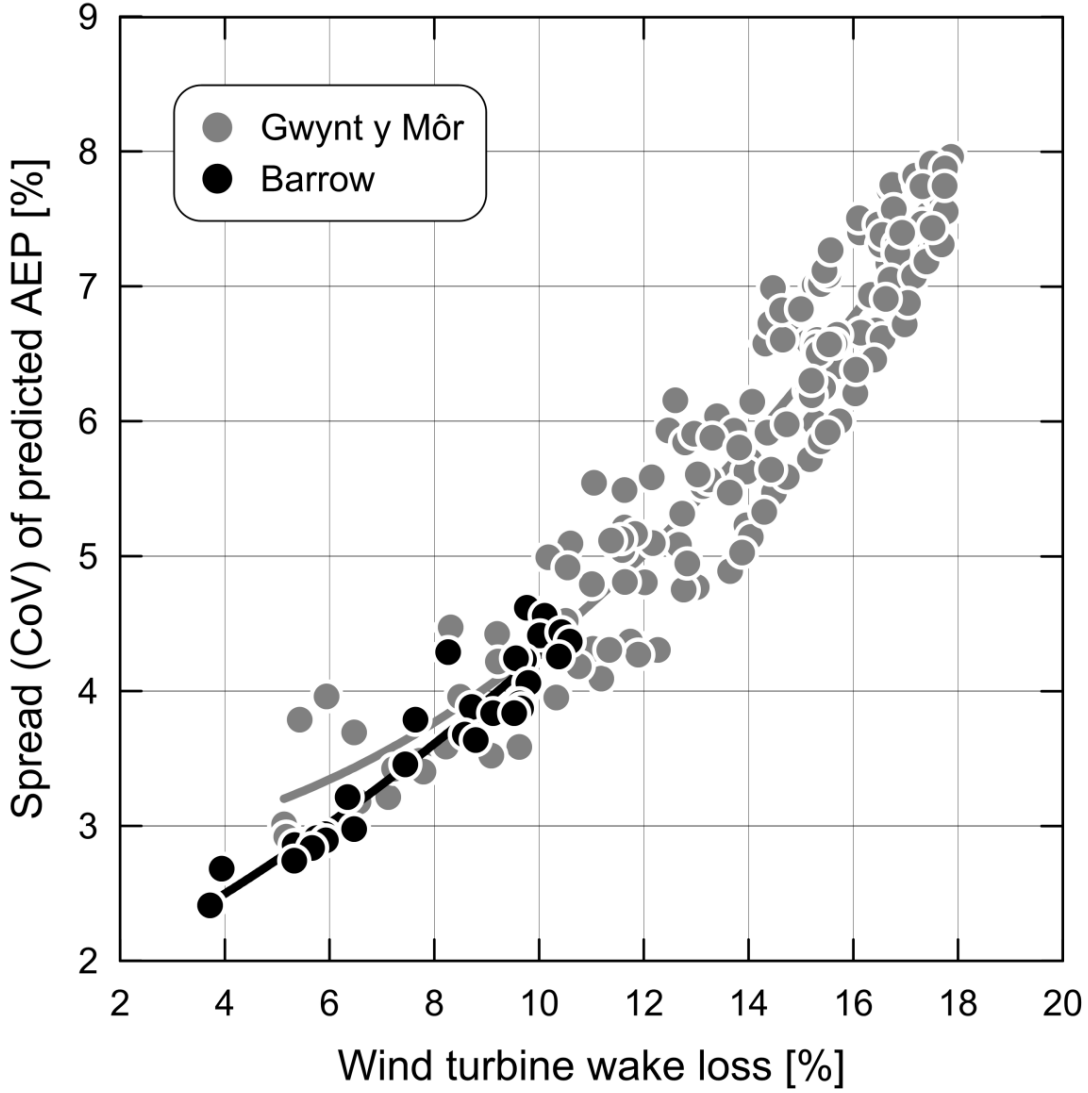
- Vertical extrapolations not so challenging
  - Mast height/hub height = 0.83-1.07
  - Profile effects less than 3% on *U*
- Methodologies used (onshore)
  - Shearing-up by ½ of the teams
  - Flow modelling by ½ of the teams
- Uncertainty (CV)
  - 10-22% on mean shear exponent
  - 0.7-3.6% on observed wind speed
- Special issues
  - 7-11% outliers on exponent value
- CREYAP results
  - Inconclusive, but a bit scary!
  - Challenging case study needed.

3 Horizontal extrapolation



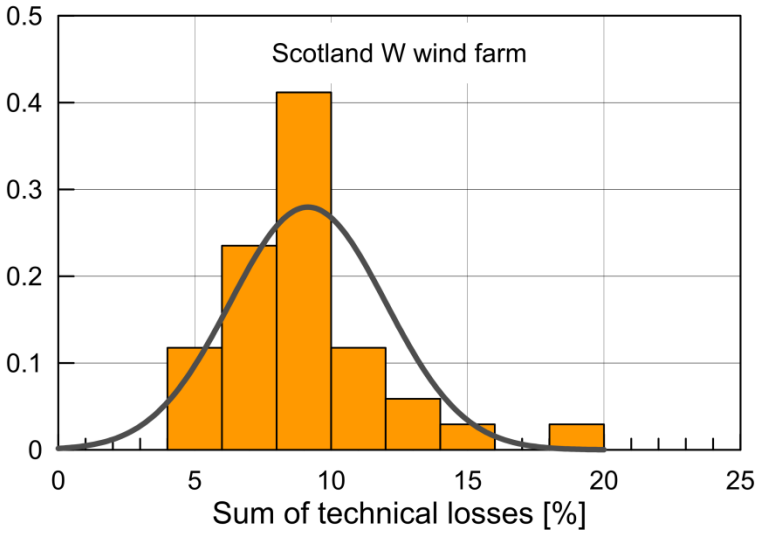
- Model results not significantly different, e.g. linearized and CFD-type flow models
- Magnitude of effect (onshore only)
  - Extrapolation: +3.2 and −8.7% of yield
  - Topographical: 22 to 23% of yield
- Methodologies used
  - Flow modelling only; many different
  - Model name and specification important
- Uncertainty
  - Spread on extrapolation high: 59-132%
- Special issues
  - Few (0-2%) outliers
- Additional results
  - Model results ranges too narrow.

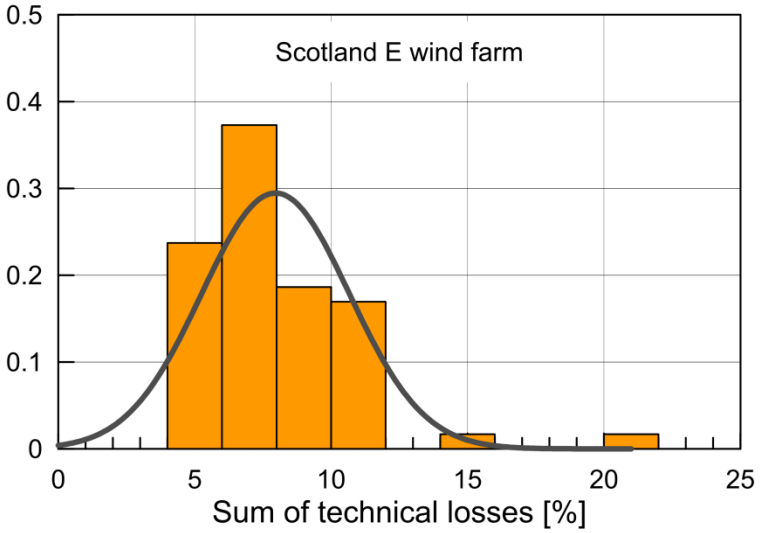
4 Wake modelling



- Wake models disagree inside wind farms: uncertainty (CV) ∝ WTG wake loss
- Wakes represent a significant wind farm loss
  - Onshore: 6-10%
  - Offshore: 8-14%
- Modelled with a separate wake model
  - Model name and specification important
  - Model configuration must be known too!
- WF wake modelling uncertainty (CV)
  - Onshore: 13-18%
  - Offshore: 16-22%
  - Uncertainty ∝ WF wake loss
- Classic models seem to provide realistic results for Barrow Offshore Wind Farm

5 Technical losses estimation





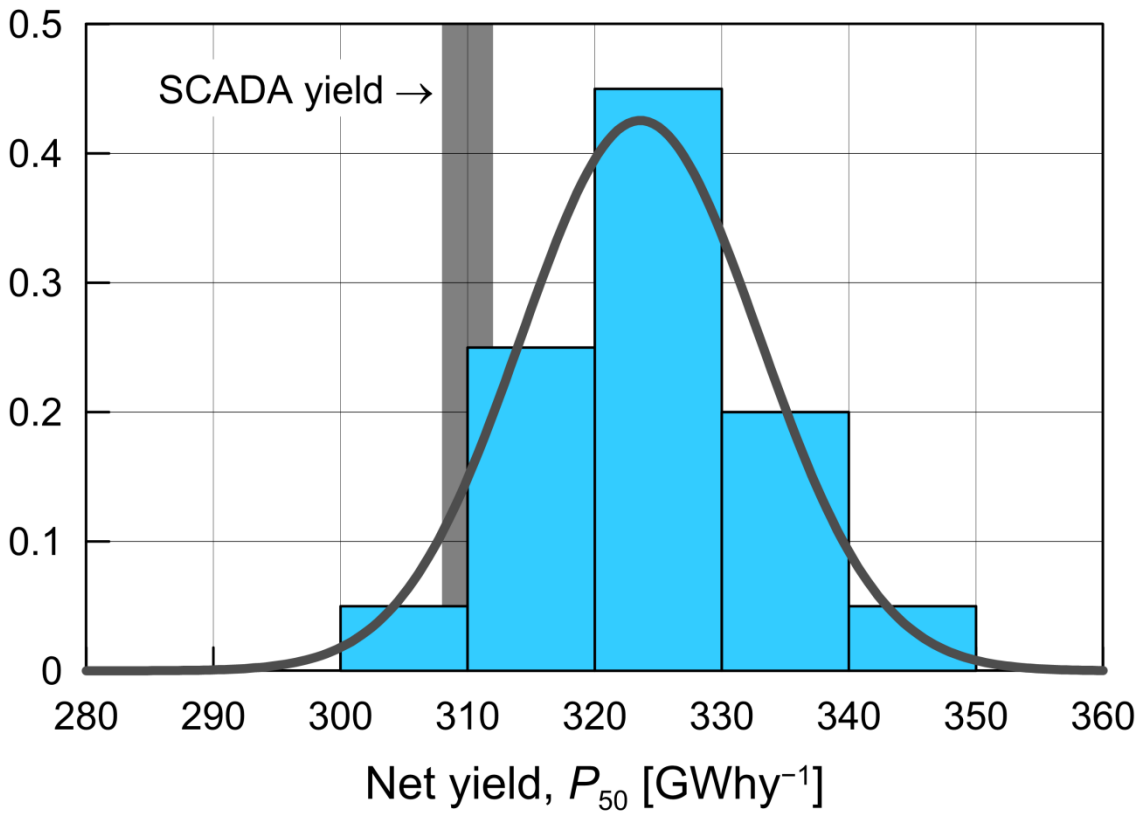
- Technical losses large and uncertain
  8-9.2% on average (onshore)
- Methodologies used
  - Not well defined at all
- Uncertainty
  - 32-34% coefficient of variation
- Special issues
  - 2-3% outliers
- Additional results
  - Calculation procedure sometimes wrong: losses added, not factored together.

6 Uncertainty estimation and calculation

Wind farm	Estimated uncertainty	CV	σ_{P50}
Onshore W Hilly/complex	11%	34%	5%
Onshore E Hilly/complex	8%	28%	6%
Offshore Gwynt y Môr	10%	29%	7%
Offshore Barrow	10%	23%	3%

- Uncertainty estimates large and uncertain
  8% to 11% on average
- Methodologies used
  - Not well defined at all
- Uncertainty
  23% to 34% coefficient of variation
- Special issues
  - About ¼ of the teams make errors when calculating P_{90} from P_{50} and uncertainty
- Additional results
  - Spread of estimates < estimated spread.

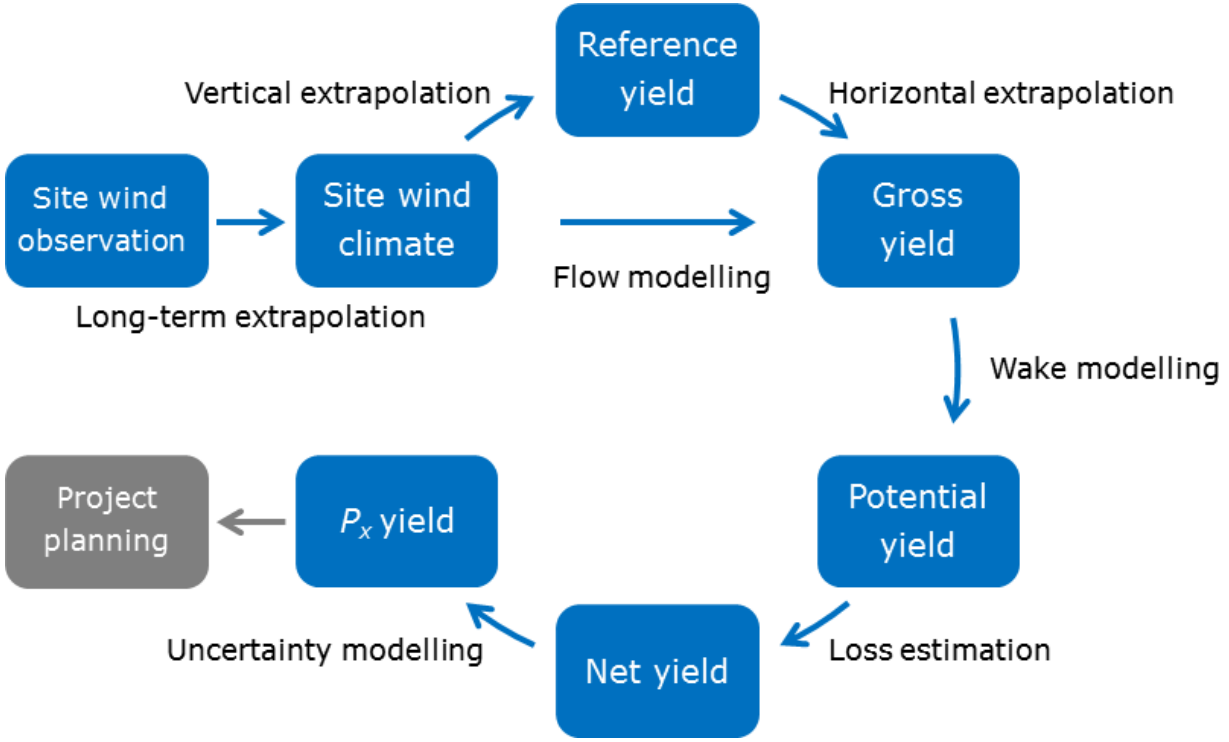
Predicted vs observed AEP



- Only Barrow provided AEP comparison
  - Estimated = 104% of observed P_{50}
  - Spread ~ 3% for net yield
  - Measured yield has an uncertainty too
- Methodologies used
  - No simple relation between methodology and how well teams perform.
- Uncertainty
  - Nice bell-shaped distribution
  - Uncertainty (CV) ~ 3%
- Special issues
  - No or fewer outliers in Barrow study
- CREYAP results
  - Results seem to improve over time.

What needs to be done?

1. Calculation, documentation and reporting
   - Robust, unambiguous framework
2. Long-term extrapolation methods
   - Well-defined and proven (NWA)
3. Uncertainty estimation and calculation
   - Framework, methodology and tools
4. Wake modelling (especially offshore)
   - Best practice based on validation data
5. Systematic technical losses estimation
   - Methodology and tools
6. Flow modelling
   - Vertical + horizontal extrapolation = flow modelling
   - Best practice based on validation data



- Future CREYAP exercises 2016-2020
  - Very steep or forested terrain
  - Tall turbines, challenging climatology, …
  - Wind conditions and site suitability
- So, the final word (as always) is…
  - High-quality wind farm data are in high demand for future studies and research!

Thank you for your attention!

Contributions by RES, Dong Energy, Iberdrola, Crown Estate, EWEA and all the teams are gratefully acknowledged!

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Land-based wind farms

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Dissemination

More than 1500 CREYAP publication downloads from DTU's web site since 2011: more than ×10 the number of submissions.

Score for the different steps – low is more important

	Scotland West	Scotland East	Onshore	Gwynt y Môr	Barrow OWF	Offshore
Long-term extrapolation	11	9	10 (1)	16	8	12 (3)
Vertical extrapolation	18	20	19 (6)	n/a	12	12 (4)
Horizontal extrapolation	14	12	13 (3)	16	18	17 (6)
Wake modelling	18	13	16 (5)	5	11	8 (2)
Technical losses	12	14	13 (2)	12	19	16 (5)
Uncertainty estimation	11	16	14 (4)	10	6	8 (1)

What needs to be done?

Land-based

1. Long-term extrapolation methods
2. Systematic technical losses estimation
3. Horizontal extrapolation
4. Uncertainty estimation and calculation
5. Wake modelling
6. Vertical extrapolation

Offshore

1. Uncertainty estimation and calculation
2. Wake modelling
3. Long-term extrapolation methods
4. Systematic technical losses estimation
5. Vertical extrapolation
6. Horizontal extrapolation